OROVILLE FERC RELICENSING (PROJECT NO. 2100)

FINAL REPORT SP-F3.1, Task 2B

EVALUATION OF THE ABILITY OF LAKE OROVILLE'S COLDWATER POOL TO SUPPORT SALMONID STOCKING RECOMMENDATIONS

REVIEW DRAFT

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1.0 SUMMARY

The objective of this task is to evaluate whether there is sufficient cold water in Lake Oroville to support current annual salmonid stocking goals of 170,000 yearling equivalent salmon. For the purpose of this analysis, the usable coldwater habitat was defined as any zone in Lake Oroville in which both the water temperature criteria of less than 18°C and the dissolved oxygen criteria of greater than or equal to 6.5 mg/L were met. Water temperature and dissolved oxygen profiles collected over 51 months at as many as 8 different sampling locations in Lake Oroville were analyzed and for each month of the period of record the volume of usable coldwater habitat at each location for which data was available was calculated. Because of the variability in the volume of usable coldwater habitat between locations, the average volume of usable coldwater habitat was calculated for each month and year of the period of record. Results suggest that even in the months and years with the lowest calculated average volume of usable coldwater habitat in Lake Oroville, the volume of usable coldwater habitat available per fish far exceeds the volume of water provided for fish in settings such as hatcheries and experimental and commercial net-pen operations. The assumptions used in calculating the average volume of usable coldwater habitat in Lake Oroville are highly conservative, almost certainly resulting in an underestimation of the actual volume of usable coldwater habitat available in Lake Oroville. Additionally, available information regarding depth distribution of forage base suggests that forage base is present in Lake Oroville in the zones in which usable coldwater habitat exists. Therefore, continued operation of the Oroville facilities in a manner consistent with current operations would be expected to result in a sufficient volume of usable coldwater habitat to support current salmonid stocking recommendations in Lake Oroville.

2.0 PURPOSE

The purpose of this task is to evaluate whether there is sufficient cold water in Lake Oroville to support current salmonid stocking goals (DWR 2003). This task is related to the Federal Energy Regulatory Commission (FERC) Relicensing of the Oroville Facilities because the amount of cold water present in Lake Oroville is determined in part by project operations and in part by external factors such as air temperature and precipitation. As such, the coldwater pool in Lake Oroville is influenced, in part, by project operations. Section 4.51(f)(3) of 18 CFR requires reporting certain types of information in the FERC application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project. The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operations. As a subtask of SP F-3.2, Task 2B fulfills a portion of the FERC application requirements by providing an analysis estimating whether there is sufficient cold water in Lake Oroville to support current salmonid stocking goals. In addition to fulfilling these requirements, the conclusions from this analysis may be used as the basis for suggesting potential resource actions relating to coldwater pool habitat for salmonids in Lake Oroville.

This task is additionally related to the FERC Relicensing of the Oroville Facilities because FERC has a long history of involvement in fish stocking in Lake Oroville. In 1977, FERC approved the California Department of Water Resources' (DWR) Oroville Facilities' Recreation plan entitled Bulletin No. 117-6 (Oroville Reservoir, Thermalito Forebay, and Thermalito Afterbay Water Resources Recreation Report), which provided plans for public utilization of project lands and waters for recreational purposes through the year 2017 (FERC 1994). In 1989, FERC recognized that DWR had not fully implemented the 1977 recreation plan, and DWR asked to file a revised recreation plan for FERC's approval, which would supersede the existing approved plan (FERC 1994). DWR filed its proposed revised recreation plan on April 20, 1990, and submitted supplementary filings on January 23, 1991, and July 3, 1991 (FERC 1994). On October 1, 1992, FERC issued an order requiring amendments to the proposed recreation plan, which was to include a proposed fish stocking plan for Lake Oroville (FERC 1994). FERC required that the specification of the fish stocking plan be determined in consultation with federal, state, and local resource agencies, other governmental entities, and interested citizen and recreation groups (FERC 1994). DWR filed the amended recreation plan on June 1, 1993, with supplemental filings following on Sept 27, 1993 (FERC 1994). In the 1993 amendments, DWR proposed an interim fisheries management plan, developed in cooperation with the California Department of Fish and Game (DFG), which specified salmonid stocking rates and a 5-year joint study to prepare a final fishery management plan (FERC 1994). The results of the 5-year joint study conducted by DFG and DWR were used to determine the optimum stocking rate for salmonids in Lake Oroville (FERC 1994). The annual stocking recommendations for Lake Oroville resulting from of the five-year study were 170,000 Chinook salmon yearling equivalents (DWR 2000). Additional information regarding the components and results of this study are described briefly in the "Background" section of this report.

This task is a component of study plan SP-F3.1, Evaluation of Project Effects on Fish and Their Habitat within Lake Oroville, its Upstream Tributaries, the Thermalito Complex, and the Oroville Wildlife Area. This study plan is designed to collect and compile baseline information characterizing the fish species composition and habitat in each of several geographic areas, including Lake Oroville. Task 2 specifically is designed to focus on Lake Oroville. Task 2A describes fish species composition in Lake Oroville, while this task, Task 2B evaluates coldwater pool availability in Lake Oroville to evaluate whether there is sufficient cold water in Lake Oroville to support current salmonid stocking goals. Task 2C evaluates the impacts of water surface elevation reductions on bass nests in Lake Oroville, and an interim report for Task 2C was submitted to the Environmental Work Group (EWG) in December 2002. Task 2D reviewed management practices and monitoring studies of sturgeon from other reservoirs. The final report for Task 2D was submitted to the EWG in December 2002.

3.0 BACKGROUND

The study area for this task is Lake Oroville. As defined in SP-F3.1, the study area includes the areas within the fluctuation zone of Lake Oroville to the high water mark (DWR 2003). The data analyzed in this task was sampled at various locations within Lake Oroville and it's tributary arms. For additional information about specific sampling locations, see the "Methods" section of this report.

In general, Lake Oroville thermally stratifies in the spring, destratifies in the fall, and remains destratified throughout the winter. Lake Oroville supports a two-story fishery, which means that it supports both coldwater and warmwater fish species that are thermally segregated for most of the year. The coldwater fish use the deeper, cooler, well-oxygenated hypolimnion, whereas the warmwater fish are found in the warmer, shallower, epilimnetic and littoral zones. When Lake Oroville destratifies, the two fishery components mix in their habitat utilization. The Lake Oroville coldwater fishery is managed as a put and grow fishery, meaning that hatchery raised fish are stocked in Lake Oroville as juveniles, with the intent that they will grow in the lake before being caught by anglers (DWR 2001). The California Department of Fish and Game

(DFG) manages the Lake Oroville coldwater fishery with the primary objectives of producing trophy salmonids and providing a quality fishery characterized by high salmonid catch rates (DWR 2000). The coldwater fishery is sustained by hatchery stocking because natural recruitment to the Lake Oroville coldwater fishery is very low. The current salmonid fishery is not self-sustaining, possibly due to insufficient spawning and rearing habitat in the reservoir and accessible tributaries, and natural and artificial barriers to migration into the upstream tributaries with sufficient spawning and rearing habitat (DWR 2001).

A variety of salmonids have been stocked in Lake Oroville beginning in 1968. From 1968 to 1978, rainbow trout (*O. mykiss*), brown trout, coho salmon, and kokanee salmon (*O. nerka*) were the principally stocked salmonids (DWR 2000). Beginning in 1979, coho and kokanee salmon were no longer stocked and Chinook salmon were stocked as a substitute (DWR 2000). Beginning in 1988, rainbow trout were no longer stocked (DWR 2000). From 1988 to 2000, brown trout and Chinook salmon were the principally stocked salmonids in Lake Oroville (DWR 2000). From 1990-2000, the Lake Oroville coldwater fishery was managed for Chinook salmon (*Oncorhynchus tshawytscha*) and brown trout (*Salmo trutta*) (DWR 2000). Recent disease concerns, including the prevalence of infectious hematopoietic necrosis virus (IHN), have prompted changes in the stocking procedures at Lake Oroville. Due to their susceptibility to IHN, Chinook salmon and brown trout are not currently being stocked. Coho salmon (*O. kisutch*) were stocked as a replacement for Chinook salmon and brown trout in order to maintain an attractive coldwater fishery in Lake Oroville, as they are less susceptible to IHN (DWR 2003).

Current annual salmonid stocking recommendations for Lake Oroville are based on a 5-year study conducted jointly by DFG and DWR in Lake Oroville (DWR 2000). The joint five-year study was conducted in order to gather data for determining the optimum stocking rate for salmonids in Lake Oroville (FERC 1994). Although there was a history of salmonid stocking in Lake Oroville prior to the initiation of this five-year study, there had never been systematic measurements to establish the effects of stocking salmonids on other reservoir fish species and to establish the optimum level of stocking (FERC 1994). The five-year joint study proposed an experimental stocking approach designed to produce a sound fish stocking policy. DFG and DWR stocked successively increased numbers of salmonids in Lake Oroville each year, while utilizing mark-recapture techniques to collect information such as angler harvest, survival, and growth (DWR 2000). Additionally, the study collected creel survey data and hydroacoustic data to assess the effects of increasing salmonid stocking on the black bass population and the forage base, respectively (DWR 2000). The study was conducted from July 1993 through June 1999, with increasing numbers of yearling equivalent Chinook salmon stocked each year (DWR 2000). A "yearling equivalent" was defined as the number of fingerlings and yearlings stocked in combination that would produce a similar angler catch if only yearlings are stocked and is based on return rates of coded wire tagged Chinook salmon in the recreational fishery (DWR 2000). The annual stocking recommendations for Lake Oroville resulting from of the five-year study were 170,000 Chinook salmon yearling equivalents (DWR 2000). This recommendation was chosen in order to provide for a quality salmonid fishery and provide for trophy fishing opportunities (DWR 2000). The objective of the stocking program is to produce salmonids great than or equal to five pounds (DWR 2000). In order to meet this objective, DFG suggested length-at-age targets for Chinook salmon at 12, 18 and 24 months of age (DWR 2000). The annual stocking recommendation of 170,000 yearling equivalent Chinook salmon was the highest stocking density which resulted attainment of length-at-age targets. These recommendations were submitted to FERC on February 15, 2000 (DWR 2000). Coho salmon are currently being stocked instead of Chinook salmon due to disease-related concerns detailed above, and the target annual stocking rate for coho is currently 150,000-170,000 coho per year (pers. com., E. See, DWR, 2003).

The amount of coldwater habitat for stocked salmonids in Lake Oroville is, in part, influenced by project operations. Project operations influence fish habitat in Lake Oroville by manipulating the amount of cold water for downstream released into the Feather River and through changes in Lake Oroville's water surface elevation necessary for flood control, water deliveries, and power generation. Cold water is taken from Lake Oroville's hypolimnion for the purpose of supplying cold water to the downstream fishery in the main channel of the Feather River, thereby potentially limiting the amount of cold water available for salmonids in Lake Oroville. Therefore, the objective of this task to evaluate whether there is sufficient cold water in Lake Oroville to support current salmonid stocking goals of annual stocking of 170,000 yearling equivalent salmon.

4.0 METHODOLOGY

Task 2B of SP-F3.1 is specifically designed to evaluate whether there is sufficient cold water in Lake Oroville to support current salmonid stocking goals. The SP-F3.1, Task 2B work plan (DWR 2003) originally specified that "*...because the amount of cold water present in Lake Oroville is determined in part by project operations and in part by external factors such as air temperature and precipitation, analysis of the extent of the cold water pool will incorporate varied hydrologic and climatic conditions by utilizing results of modeled exceedance estimates obtained from SP-E7. To estimate whether or not there is sufficient cold water in Lake Oroville to support current stocking recommendations for the coldwater fishery, exceedance graphs estimating the probability that there will be a certain volume of water below a certain temperature using the area-capacity curve for Lake Oroville will be obtained from SP-E7.*" Once the volume of water was calculated, the following analysis was to be conducted: "*The volume of cold water available will be divided by the number of coldwater fish required to meet stocking goals to determine the volume of cold water available per fish. The amount of cold water available per fish will be calculated for months and conditions (hydrologic and climatic) simulated in SP-E7. A literature review of laboratory/field studies, stocking reports, and other agency reports will be conducted in order to generate an estimate of the minimum [i.e., lowest maximum] fish density. The loading density recommended by the literature review will then be compared to the calculated density of fish in Lake Oroville's cold water pool to determine whether there is enough cold water to support the stocking recommendations.*"

The Study Plan for Task 2B of SP-F3.1 originally suggested that simulated model output from SP-E7 be used in order to calculate the volume of cold water available in Lake Oroville. However, after reviewing limnological depth profiles of water temperature and dissolved oxygen, actual limnological profiles showing the concurrent distribution of water temperatures and dissolved oxygen by depth were utilized to provide the foundation for the calculation of the volume of the usable coldwater habitat in Lake Oroville. The reason for the change in source data is described in detail below in "Data Sources" section of this report. In addition to using water temperature criteria to define the volume of coldwater pool usable by salmonids, a dissolved oxygen criterion was also added to this analysis, as described in detail in the "Definition of Usable Coldwater Habitat" section of this report. With the exception of the relatively minor change in data sources and the addition of dissolved oxygen as a component of the analysis, the remainder of the analysis was conducted in accordance with the original study plan proposal. A detailed description of the analytical procedures utilized in the analyses is provided below.

4.1 DEFINITION OF USABLE COLDWATER HABITAT

The conceptual approach utilized in this analysis required defining the usable coldwater salmonid habitat using physiochemical characteristics which had been measured over a sufficient period of record to provide a meaningful analysis which captured variation in hydrologic, climatic, and operational conditions. "Usable coldwater habitat" is defined in that analysis as the zone of water within a lake that meets the physiochemical requirements for coldwater fish habitat. The layer of usable coldwater habitat within a lake that meets these requirements can be defined by several criteria, including water temperature and dissolved oxygen. Because this task was focused on assessing water temperature (i.e., availability of sufficient cold water to support salmonid stocking goals), and because dissolved oxygen concentrations are related to thermal stratification, both water temperature and dissolved oxygen criteria were used to define the usable coldwater salmonid habitat for this analysis. Although not identified in the original work plan, dissolved oxygen is an essential component of usable habitat because dissolved oxygen, along with water temperature, is a physiochemical variable for which salmonids exhibit a relatively narrow and specified physiological tolerance. Both water temperature and dissolved oxygen were considered because it could be possible that water temperature may appropriate for salmonid utilization at a certain depth, but that dissolved oxygen concentrations may not be appropriate for salmonid utilization at that same depth. Considering only water temperature may have resulted in calculating "usable" habitat that, while appropriate for salmonids with respect to water temperature, may in fact not have been appropriate for salmonids when dissolved oxygen concentrations were additionally considered. Therefore, both water temperature and dissolved oxygen were used to define the usable coldwater salmonid habitat in Lake Oroville for this analysis.

The water temperature and dissolved oxygen criteria chosen for this analysis are based on the most stringent recommended EPA criteria for protection of aquatic life for water temperature and dissolved oxygen for growth of adult and juvenile salmonids. The water temperature criteria chosen is based on the weekly maximum average water temperature, as no monthly criteria is recommended by the EPA for protection of aquatic life. EPA suggests two types of criteria for water temperature for coho salmon: maximum weekly average water temperature for growth of juvenile and adult coho salmon (18°C) and maximum weekly average water temperature for survival of juvenile and adult coho salmon (24°C) (EPA 2002). 18°C was chosen as the water temperature used to define the upper layer of the usable coldwater salmonid habitat for this analysis for several reasons. It was chosen because it was a more conservative estimate than the 24°C water temperature criteria for survival of juvenile and adult coho salmon. Additionally, of all the salmonids for which specific criteria are recommended, coho salmon had the most stringent water temperature recommendations and coho are currently being stocked in Lake Oroville. For the purpose of this analysis, water with a temperature less than 18°C was considered usable coldwater salmonid habitat, provided dissolved oxygen concentrations were also usable.

The dissolved oxygen criteria chosen for this analysis is based on the 30-day mean criterion for protection of coldwater aquatic life for juvenile and adult lifestages. EPA suggests three types of criteria for dissolved oxygen for coldwater aquatic life: the 1 day minimum criteria (4.0 mg/L dissolved oxygen), the 7 day mean minimum criteria (5.0 mg/L dissolved oxygen), and the 30-day mean criteria (6.5 mg/L dissolved oxygen) (EPA 2002). 6.5 mg/L was chosen as the dissolved oxygen concentration used to define the layer of the usable coldwater salmonid habitat for this analysis for several reasons. It was chosen because it was a more conservative estimate than the other two recommended criteria. Additionally, this criteria is designed for the protection of all coldwater aquatic life, therefore selection of this criteria results in a definition of usable coldwater salmonid habitat that is appropriate for both Chinook salmon and coho salmon. For the purpose of this analysis, water with dissolved oxygen concentrations greater than or equal to 6.5 mg/L dissolved oxygen was considered usable coldwater salmonid habitat, provided water temperature conditions were also usable.

For the purpose of this analysis, the usable coldwater habitat was defined as any zone in Lake Oroville in which both the water temperature criteria of less than 18°C and the dissolved oxygen criteria of greater than or equal to 6.5 mg/L were met concurrently. Additional detail regarding application of this criteria to calculation of the volume of useable coldwater habitat is presented in the "Calculation of Volume of Usable Coldwater Habitat" section of this report.

4.2 CHARACTERIZATION OF WATER TEMPERATURE AND DISSOLVED OXYGEN IN LAKE OROVILLE

The original SP-F3.1 Task 2B study plan anticipated using modeled exceedance estimates obtained from SP-E7 to characterize the volume of coldwater available in Lake Oroville. This model output includes information such as the likelihood of a given volume of water of a given water temperature occurring in a given month. Although this data set offered substantial information regarding water temperature, the dissolved oxygen criteria component of the analysis could not be reliably integrated into this set of data. Originally, 51 months of limnological data from as many as eight sampling locations throughout Lake Oroville were examined in order to generate a "typical" monthly dissolved oxygen profile for Lake Oroville that could be used in conjunction with the modeled water temperature data from SP-E7. This "typical" dissolved oxygen profile would have been used to determine the depth from the water surface at which dissolved oxygen reaches less than 6.5 mg/L for each month. However, after examining the limnological data, it became obvious that the heterogeneity in the water temperature and dissolved oxygen profiles between sampling locations and between years, even in any given month, would preclude a reasonable estimation of a "typical" applicable dissolved oxygen profile to superimpose over the modeled water temperature exceedance curve generated by SP-E7. The variability in the relationship between water temperature and dissolved oxygen was too great to generalize a depth below water surface at which dissolved oxygen would reach less than 6.5 mg/L. **Figure 1** below illustrates the heterogeneity of the dissolved oxygen profiles at two different sampling locations in Lake Oroville in September. As illustrated below, the dissolved oxygen concentrations in each of the Septembers sampled vary not only by year, but all between sites within any given year. For example, on September 9, 1994, all the dissolved oxygen concentrations measured near the face of the Oroville Dam were above 8.4 mg/L, while on the same date, measure dissolved oxygen concentrations fell below 6.5 mg/L over 3 meters in the vertical profile.

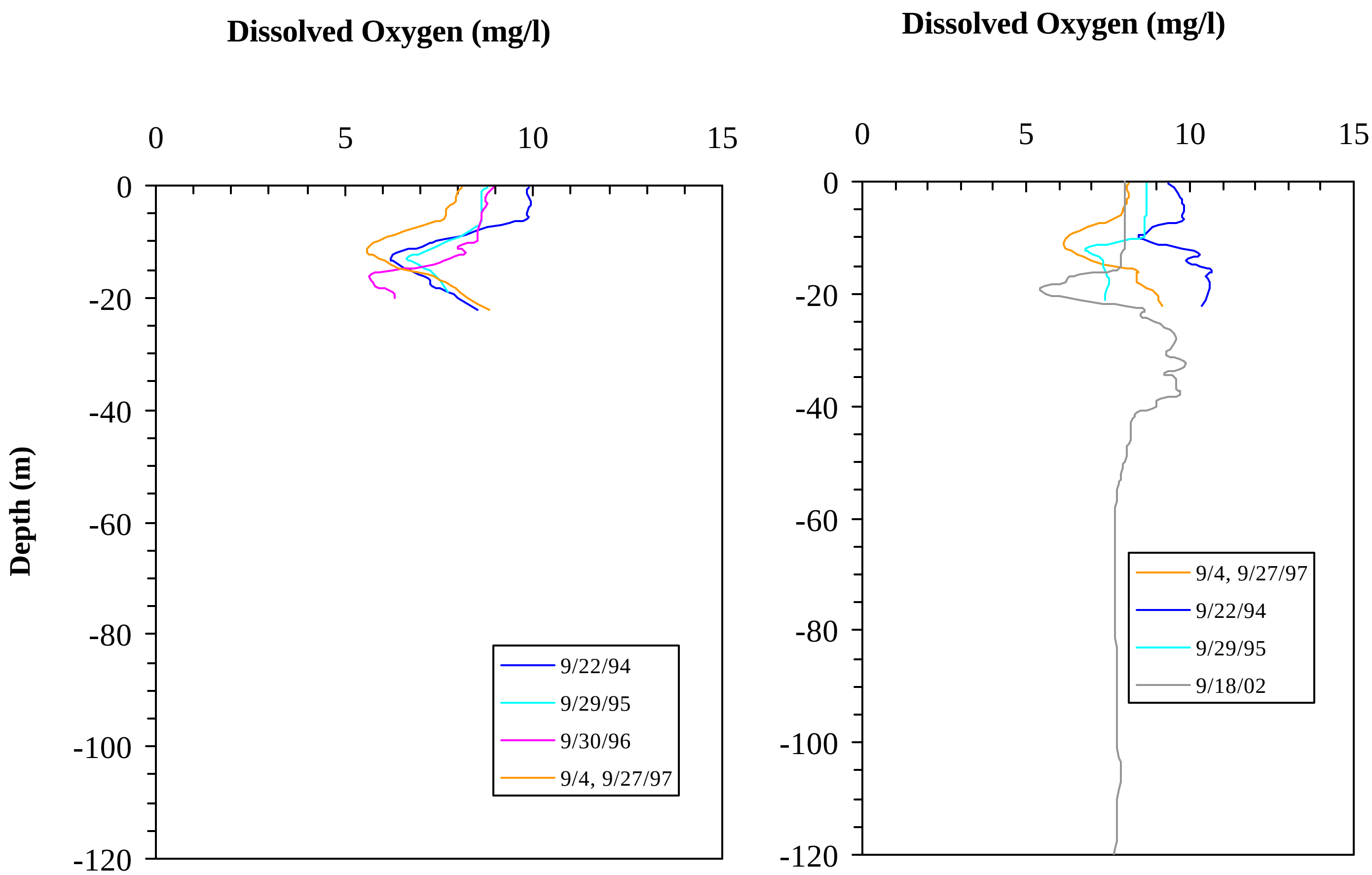

Figure 1. Dissolved oxygen profiles by depth near the face of Oroville Dam (right) and at Bidwell Bar Bridge sampling station (left) for the month of September including all Septembers sampled over the period of record at these two locations.

In addition to the disadvantages to generating a "typical" dissolved oxygen concentration profile described above, the model output from SP-E7 describing water temperatures is descriptive of conditions only near the face of Oroville Dam. Because of the heterogeneity observed in the limnological data, relying on water temperatures in just one location in Lake Oroville may result in inappropriate representation of water temperatures elsewhere in the reservoir. In order to prevent generalizations about physiochemical conditions of the reservoir at various locations, 51 months of real limnological data at eight sampling locations within Lake Oroville illustrating the coincident relationship between water temperature, dissolved oxygen, and depth were used as the source data onto which the water temperature and dissolved oxygen criteria were superimposed to determine the volume of usable coldwater salmonid habitat.

Sampling locations. Water temperature and dissolved oxygen profiles were collected at eight different sampling locations in Lake Oroville. Sampling stations are located near the face of Oroville Dam, in the main body of Lake Oroville, on the North Fork Arm of Lake Oroville, on the Middle Fork Arm of Lake Oroville, on the South Fork Arm of Lake Oroville, and at Bidwell Bar Bridge near the confluence of the Middle and South Fork Arms of Lake Oroville. There are two separate sampling stations that are representative of conditions near the face of the Oroville Dam (Oroville Dam near face and Oroville Dam sampling stations). Similarly, two sampling sites exist in the North Fork Arm of Lake Oroville (Goat Ranch and North Fork Arm sampling stations). Eight different sampling locations exist, representing 6 general geographic areas in Lake Oroville. The location of each sampling station is represented below in **Figure 2**.

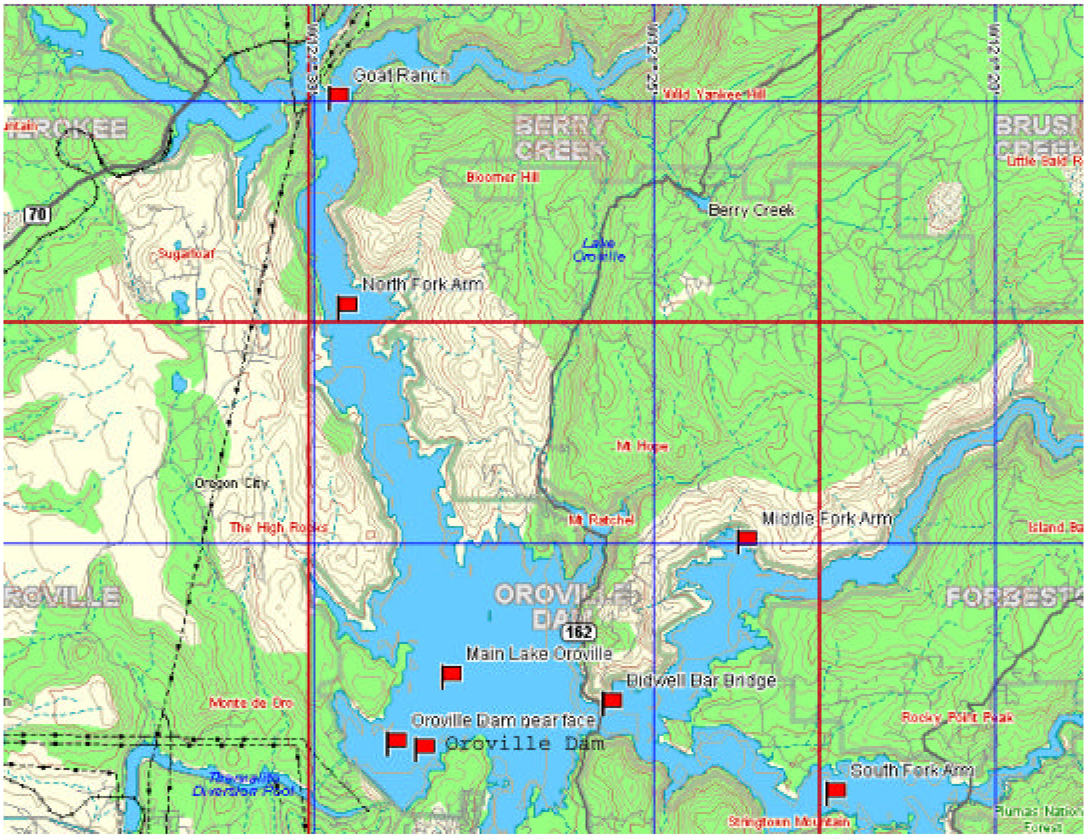

Figure 2. Locations of Lake Oroville water temperature and dissolved oxygen sampling stations.

Period of record. The water temperature and dissolved oxygen profiles used in this analysis to characterize Lake Oroville were collected over 51 months from May 1993 to September 2002 by DWR reservoir biologists and water quality scientists. Data was not collected continuously (i.e., each month of the year) during this time period; however, the data utilized in this analysis represents the longest running series of data describing the relationship between water temperature and dissolved oxygen and the best available data describing this relationship taken in Lake Oroville. Although data was not collected every month of the year, data was collected in most summer and early fall months over the sampling period, which represents the period in which the volume of usable coldwater habitat for salmonids in Lake Oroville is most likely to be the smallest due to a combination of warm water temperatures and potential oxygen depletion associated with thermal stratification. Although data was collected from 1999 through 2002, no data was collected in 2000 or 2001. The sampling program that originated in May 1993 was discontinued in November of 1999 (pers. com., E. See, DWR, 2003). In 2002, water temperature and dissolved oxygen data collection was re-initiated under SP-W1.

Water temperature and dissolved oxygen data were not collected at the same locations throughout the entire period of record. From 1993 through 1999, sampling occurred at three locations including the Oroville Dam near face sampling station, the Goat Ranch sampling station, and the Bidwell Bar Bridge sampling station. In 2002, the Bidwell Bar Bridge sampling station was not monitored, but the Middle Fork Arm sampling station, the South Fork Arm sampling station, North Fork Arm sampling station, and the Main Lake Oroville sampling station were added as new monitoring stations. In 2002, the location of the Oroville Dam near face sampling station was moved slightly to the east and renamed the Oroville Dam sampling station. The Oroville Dam sampling station and Oroville Dam near face sampling station are both considered representative of the geographic region of Lake Oroville near the face of Oroville Dam, and the two sampling locations in the North Fork Arm of Lake Oroville are considered representative of the geographic region of Lake Oroville in the North Fork Arm.

Complete limnological profiles including water temperatures and dissolved oxygen were not always collected at all sampling locations during any given data collection event. In some cases water temperature profiles were collected, but dissolved oxygen concentrations were not recorded. Limnological profiles containing only water temperature data were not utilized in this analysis because the definition of usable coldwater habitat utilized specifies both dissolved oxygen and water temperature criteria. Therefore, only limnological profiles containing both water temperature and dissolved oxygen data were utilized. The months for which both water temperature and dissolved oxygen data are available and the locations at which data were collected in each month are illustrated in **Table 1** below.

<u>Data periodicity and conditioning</u>. Water temperature and dissolved oxygen profiles were collected approximately once monthly at various locations throughout Lake Oroville from 1993-1999. As described above and illustrated in Table 1, data were not available for every month of every year. As a result, the analysis considered only the months and years in which profiles showing the relationship between water temperature and dissolved oxygen were available. In many cases, only one sampling event occurred during each calendar month. Due to a lack of daily and weekly data, when limnological profiles were collected in one day of any given month this analysis assumed that the data collected on that day was sufficient to representative the thermal and chemical stratification at that location in that month for that year. Although sampling generally occurred once during each calendar month sampled from 1993-1999, in 2002, data was generally collected twice per month in 2002.

In cases where two or more water temperature and dissolved oxygen profiles were available for any given month, year, and location, multiple water temperature and dissolved oxygen profiles were represented by one nonlinear fitted curve obtained through the S-Plus function *loess* (MathSoft 1999) which is a locally weighted regression smoothing. This procedure is a nonparametric regression procedure that fits a curve to the data points (e.g., water temperature and depth pairs) locally, so that at any point (e.g., measured depth) the response curve at that point depends only on the observations (e.g., water temperatures) at that point and some specified neighboring points, indicated as a proportion, termed span, that must be greater than 0 and smaller than 1. In general, the greater the span, the smoother the resulting curve. In the current analysis, whenever the function *loess* was used, a span of 0.2 was utilized to provide a less smooth fitted depth profile that would be closer to the observed water temperature and dissolved oxygen readings. The *loess* curve was used to combine dissolved oxygen and water temperature profiles because a mathematic average of water temperature and dissolved oxygen concentration by depth would misrepresent the data in cases where inconsistencies exist in the available data set, such as inconsistent sampling depths and intervals, as described below. *Loess* curves were utilized only to graphically represent water temperature and dissolved oxygen data in Appendix A and were not used in the calculation of usable coldwater habitat.

Table 1. Months and years for which water temperature and dissolved oxygen profiles are available by location. Data are available for months, years and locations shaded black.

	1993												1994											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Bidwell Bar Bridge					■	■		■		■		■	■		■				■		■	■		
Goat Ranch/NF Arm					■	■		■		■		■	■		■				■		■	■		
Main Lake																								
Middle Fork																								
Oroville Dam near face/Oroville Dam					■	■		■		■		■	■		■				■		■	■		
South Fork																								
	1995												1996											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Bidwell Bar Bridge					■			■			■	■					■	■	■	■			■	
Goat Ranch/NF Arm					■			■	■	■	■	■					■	■	■				■	
Main Lake																								
Middle Fork																								
Oroville Dam near face/ Oroville Dam					■			■			■	■					■	■	■	■			■	
South Fork																								
	1997												1998											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Bidwell Bar Bridge	■		■	■		■	■	■	■		■		■		■	■		■	■				■	
Goat Ranch/NF Arm	■		■	■		■	■	■	■		■		■		■	■		■	■			■	■	
Main Lake																								
Middle Fork																								
Oroville Dam near face/Oroville Dam	■			■		■	■	■	■		■		■		■	■		■	■				■	
South Fork																								
	1999												2000											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Bidwell Bar Bridge		■		■		■	■	■		■	■													
Goat Ranch/NF Arm		■		■		■	■	■		■	■					■	■	■	■	■	■			
Main Lake																■	■	■	■	■	■			
Middle Fork																■	■	■	■	■	■			
Oroville Dam near face/Oroville Dam		■		■		■	■	■		■	■						■	■	■	■	■	■		
South Fork																■	■	■	■					

The depth of water sampled during generation of limnological profiles varied by location, sampling event, and year. Water temperature and dissolved oxygen data collected from 1993 to 1999 was typically collected from the surface of Lake Oroville to a depth of 20 - 22 m (65.6 - 72.2 ft) below the water surface. In 2002, water temperature and dissolved oxygen data were collected at greater depths, with data collected to depths ranging from 56 to 170 m (184 - 558 ft) below the water surface depending upon the sampling station location. The depth increments at which water temperature and dissolved oxygen data were collected were not always uniform and varied between sampling location and sampling date. In some cases, water temperature and dissolved oxygen data were collected every meter. In other cases, water temperature and dissolved oxygen were collected every other meter. In these cases, data was sometimes collected at the odd meters (i.e., 1, 3, 5, 7 m) and other times collected at even meters (i.e., 2, 4, 6 m). In order to make data comparable and consistent, when water temperature and dissolved oxygen data were taken every other meter, the water temperature and dissolved oxygen data for the omitted meter was calculated by taking the average of the water temperature and dissolved oxygen measurement in the meter above and below the meter with omitted data.

4.3 CALCULATION OF VOLUME OF USABLE COLDWATER HABITAT REQUIRED TO SUPPORT CURRENT SALMONID STOCKING GOALS

As specified in SP-F3.1, a literature review of laboratory/field studies, stocking reports, and other agency reports was conducted in order to generate an estimate of lowest maximum reported fish density (DWR 2003). The lowest maximum loading density recommended by the literature review was then be used to the calculated density of fish in Lake Oroville's cold water pool to determine whether there is enough cold water to support the stocking recommendations (DWR 2003). To this end, two literature reviews were performed. In the first review, published hatchery-pond rearing densities for Chinook and coho salmon were reviewed and summarized (see Appendix B). Summarized information included the fish species, the pond density (fish/m^3), the final average fork length or weight of fish, the rearing period (dates), the hatchery name, the physical characteristics of the rearing pond, and the reference. In the second literature review, published densities for salmonids grown in experimental and commercial net-pens and cages were reviewed (see Appendix C). Information gathered in this search consists mostly of Atlantic salmon reared from smolt to commercial adult sizes in marine net-cages. Additional information regarding Chinook and coho salmon, as well as three trout species was also reviewed and summarized. Summarized information included the fish species, the lifestage of reared fish, the number of fish reared, the stocking density (fish/m^3), the volume of water, the description of rearing facilities, the location of the facilities, and the reference.

In order to calculate the volume of usable coldwater habitat required to support current salmonid stocking goals, the number of fish required to meet stocking goals (fish) was divided by the lowest maximum reported stocking density from the literature review (fish/m^3) to obtain the volume of water (m^3) that would be required if the number of fish required to meet stocking goals was stocked at the lowest maximum reported stocking density. The number of fish required to meet stocking goals was determined using the following rationale. The current annual stocking goal for salmonids in Lake Oroville is 170,000 salmon yearling equivalents (DWR 2000). During the joint five-year study conducted to establish stocking recommendations, very few salmon (0.25%) in Lake Oroville survived past 36 months of age (DWR 2000). Therefore, for the purpose of this analysis, 3 stocking year-classes (a total of 510,000 salmon) were assumed to be in Lake Oroville at any given time. This estimate of the number of total salmon in Lake Oroville at any given time is also highly conservative because it assumes no mortality of stocked fish. The lowest maximum fish density reported in the literature reviews was selected because the literature reviews focused on hatcheries and commercial net-pen operations, facilities that are generally considered space-limited, as opposed to food-limited. The lowest maximum densities in systems that are generally considered space-limited represents a measure of the volume of water required if space is the primary variable being considered. Thus, the lowest maximum loading density reported in these settings would constitute a very conservative estimate of the amount of volume of water required per fish, if food were not limiting.

4.4 CALCULATION OF VOLUME OF USABLE COLDWATER HABITAT

For the purpose of this analysis, the usable coldwater habitat was defined as any zone in Lake Oroville in which both the water temperature criteria of less than 18°C and the dissolved oxygen criteria of greater than or equal to 6.5 mg/L were met. In order to determine the volume of usable coldwater habitat available, each month and year in which water temperature and dissolved oxygen profiles were available at any site was analyzed. Every limnological profile containing both water temperature and dissolved oxygen at each site was examined, and the range of depths from the water surface at which water temperature was less than 18°C and dissolved oxygen was greater than or equal to 6.5 mg/L was identified.

For each layer of water in which water temperature and dissolved oxygen criteria were satisfied, the depth from surface was subtracted from the water surface elevation to yield the water surface elevations (distance in feet from mean sea level) at which usable coldwater salmonid habitat was present. The reservoir elevations at which usable coldwater habitat existed was applied to the elevation-capacity curve (obtained from SP-E7) and used to determine the volume of water usable coldwater habitat on that day. As described above, due to a lack of daily and weekly data, when limnological profiles were collected in one day of any given month this analysis assumed that the data collected on that day was sufficient to representative the thermal and chemical stratification at that location in that month for that year. In cases where only one limnological profile was available for any month and site, the volume of usable coldwater habitat calculated on that day was considered representative for that month and year at that site. In cases where more than one limnological profile was available for any month and site, the volume of usable coldwater habitat calculated on all days in that month and year was averaged to obtain an average volume of usable coldwater habitat for that month and year at that site. Because of the variation in the volume of usable coldwater habitat available at different locations throughout the reservoir for each month and year, the volume of usable coldwater habitat at all locations sampled for any given month and year was averaged to arrive at an average volume of usable coldwater habitat in Lake Oroville for each month and year.

4.5 Comparison of Volume of Usable Coldwater Habitat per Fish in Lake Oroville to Volume of Coldwater per Fish Provided in Other Settings

The lowest maximum loading density reported through the literature review was compared to the fish density that would result in Lake Oroville when the number of fish required to support the salmonid stocking goals are planted. The calculated volume of water (m^3) that would be required if the number of fish required to meet stocking goals was stocked at the lowest maximum stocking density reported was compared with the calculated average volume of usable coldwater habitat in Lake Oroville in order to determine whether there was sufficient coldwater habitat to support stocking goals. The calculated average volume of usable coldwater habitat in Lake Oroville in the month and year with the smallest volume of usable coldwater habitat was divided by the calculated volume of water (m^3) that would be required if the number of fish required to meet stocking goals was stocked at the lowest maximum stocking density reported in order to assess whether the volume of usable coldwater habitat was sufficient, even in the month and year with the smallest volume of usable coldwater habitat, to support stocking goals.

5.0 RESULTS AND DISCUSSION

5.1 Characterization of Water Temperature and Dissolved Oxygen in Lake Oroville

Water temperature and dissolved oxygen data profiles from the sampling locations depicted in Figure 2 for each month and sampling station are presented in Appendix A. For ease of presentation, all sampling events in any given month over the period of record at a given site are represented on one graph. Water temperature and dissolved oxygen data for the Oroville Dam sampling station and Oroville Dam near face sampling station are both presented on the same graph, as are water temperature and dissolved oxygen data for the Goat Ranch and North Fork Arm sampling stations. Water temperature and dissolved oxygen data collected in each calendar month and each geographic region in Lake Oroville is presented on one graph. The variation in water temperature and dissolved oxygen profiles between sampling stations can be seen by comparing water temperature and dissolved oxygen profiles collected at different sampling stations for any month. On each graph, the water temperature criteria of 18°C and the dissolved oxygen criteria of 6.5 mg/L used to define usable coldwater habitat is represented by a vertical line for ease of comparison of measured water temperature and dissolved oxygen data to the criteria.

5.2 Volume of Usable Coldwater Habitat Required to Support Current Salmonid Stocking Goals

A brief summary of the results of the two literature reviews performed to determine the lowest maximum stocking density used in this analysis is provided below. In the first review, published hatchery-pond rearing densities for Chinook and coho salmon were reviewed and summarized. Summarized information included the fish species, the pond density (fish/m^3), the final average fork length or weight of fish, the rearing period (dates), the hatchery name, the physical characteristics of the rearing pond, and the reference. In hatchery ponds (or raceways) the temperature, rate of inflow (liter/sec) and general water quality is monitored and under relative control, and sufficient food is provided. The densities per pond or raceway are consistently high. The stages reared are typically emergent fry or larger juveniles that are grown until they reach an adequate size for loading into rivers or reservoirs or for transportation to release sites as fingerlings or yearlings (and occasionally as smolts). The results of this search are summarized in Appendix B. In summary, recommended hatchery stocking densities varied according the species of fish reared and the size to which fish were reared. To rear juvenile Chinook salmon from initial individual weights ranging between 2 and 8.6 g to final individual weights ranging between 5.4 and 17.8 g, hatchery rearing-densities ranged between 389 and 3,742 juveniles/m^3, with an average of 1,446 juveniles/m^3. To rear juvenile Chinook salmon to larger weights ranging between 28.2 and 133.5 g, hatchery rearing-densities ranged between 50 and 436 juveniles/m^3, with an average of 230 juveniles/m^3. To rear coho salmon, from initial sizes of 2.4 to 9.1 g to final sizes from 9.1 to 28.4 g, pond densities have ranged from 135 to 2,135 juveniles/m^3, with an average of 791 juveniles/m^3. The lowest recommended stocking density of the studies reviewed was 50 Chinook salmon juveniles/m^3.

In the second literature review, published densities for salmonids grown in experimental and commercial net-pens and cages were reviewed. Information gathered in this search consisted mostly of Atlantic salmon reared from smolt to commercial adult sizes in marine net-cages. Additional information regarding Chinook and coho salmon, as well as three trout species was also reviewed. The results of this search are summarized in Appendix C. Densities were in general considerably smaller than those for hatchery ponds, with the densities from experimental cages usually smaller than those for commercial cages. The densities used to raise smolt Atlantic salmon in commercial net-pens and cages ranged from 2 to 40 smolt/m^3 with an average of 14 smolt/m^3. The densities used to raise kelt Altantic salmon in experimental cylindrical net-cages ranged from 1 to 6 kelt/m^3. The densities for coho smolts ranged between 6 to 160 smolt/m^3 with an average of 50 smolt/m^3. Those for Chinook fingerlings ranged between 2 to 44 juveniles/m^3. The average net-pen density for fingerling and smolts salmonids was 22 juveniles/m^3. The lowest maximum density reported was 1 kelt/m^3. A kelt is a post-spawned grilse and the kelt in the experiment cited weighed approximately 2.8 lbs.

Because 1 fish/m^3 was the lowest stocking density recommended in any reference researched, and therefore represents a very conservative estimate of the number of fish that may be stocked in a given volume of water, a density of 1 fish/ m^3 was utilized to estimate the volume of water (m^3) that would be required if the number of fish required to meet stocking goals was stocked at the lowest maximum reported stocking density. The following calculation was therefore conducted, as described in the "Methodology" section of this report: 510,000 fish / (1 fish/m^3) = 510,000 m^3 of water required to stock 510,000 fish at the minimum recommended stocking density. If the number of fish stocked in Lake Oroville at any given time (510,000 fish) were stocked at the lowest maximum density reported from the review of literature from hatcheries and experimental and commercial net-pen operations, the volume of coldwater habitat required would be 510,000 m^3, or 413 acre-feet of water.

5.3 VOLUME OF USABLE COLDWATER HABITAT IN LAKE OROVILLE

The average volume of usable coldwater habitat at all locations sampled for any given month and year was calculated and is presented in **Figure 3** and **Figure 4** below. The average volume of usable coldwater habitat for each calendar month over the period of record is illustrated in Figure 3, while the average volume of usable coldwater habitat by month from May 1993 through October 2002 is illustrated in Figure 4.

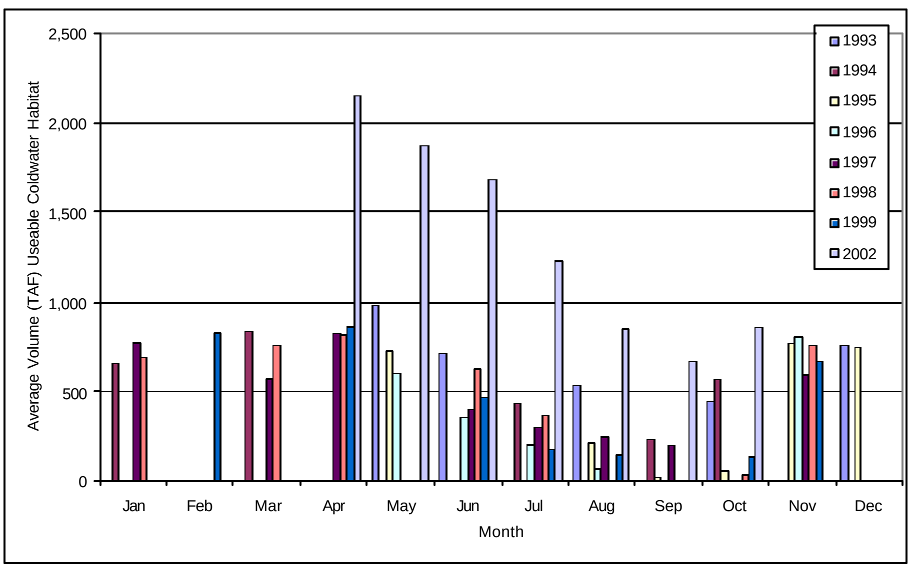

Figure 3. Average volume of usable coldwater habitat (TAF) in Lake Oroville for each calendar month over the period of record.

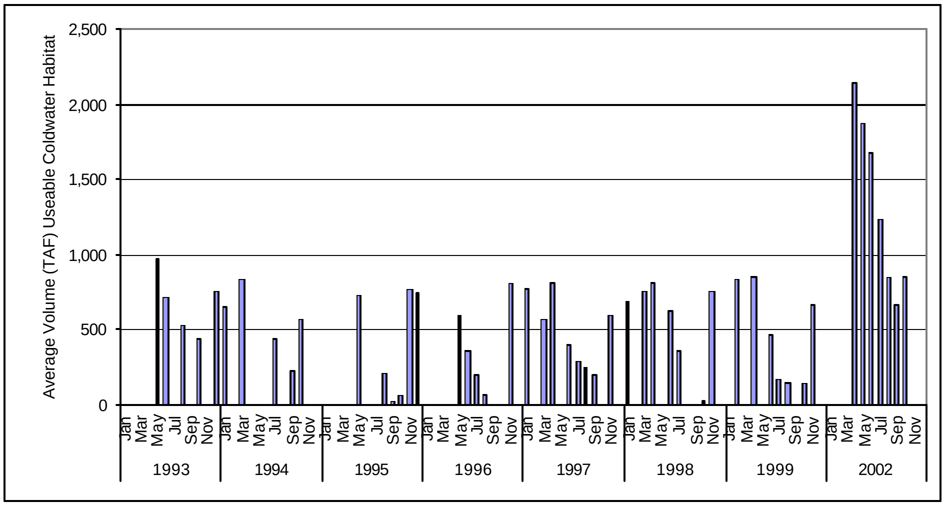

Figure 4. Average volume of usable coldwater habitat (TAF) in Lake Oroville by month from May 1993 to October 2002.

Several trends are evident with regard to the average volume of usable coldwater habitat in Lake Oroville. The volume of usable coldwater habitat is smallest in August, September, and October, as illustrated in Figure 3. This result is expected because in the summer months, water temperature is higher in the summer months than in other months. This may lead to decreased average volume of usable coldwater habitat in comparison to other months because of a greater volume of water exceeding the 18°C criteria used to define the usable coldwater pool. Additionally, thermal stratification in the summer provides the opportunity for oxygen depletion below the thermocline. This may result in a decreased volume average of usable coldwater habitat in comparison to other months because of a greater volume of water that does not meet the 6.5 mg/L dissolved oxygen criteria. In the months following fall overturn and prior to establishment of thermal stratification in early summer (i.e., late fall through late spring months), the cool water temperatures combined with the mixing that results when thermal stratification is absent results in relatively large volume of water meets the criteria for usable coldwater habitat compared to the volume of water that meets the criteria for usable coldwater habitat in the summer months. These trends in seasonal average volume of usable coldwater habitat in Lake Oroville occur in each year for which water temperature and dissolved oxygen profiles are available.

In addition to the seasonal variations in average volume of usable coldwater habitat in Lake Oroville, there is also variation in the average volume of usable coldwater habitat based on year. Interestingly, the volume of usable coldwater available from November through April throughout the period of record is similar regardless of year, excepting 2002. In 2002, the seasonal trend described above in which the average volume of usable coldwater habitat is lowest in the summer months occurs (Figure 3), but in general, the average volume of usable coldwater habitat is much greater in 2002 than in other years (Figure 4). In 2002, the average volume of usable coldwater habitat in August in Lake Oroville is 850 TAF, which is a larger volume that the volume of usable coldwater habitat in some fall, winter, and spring months in other years. This result is an artifact of only shallow water sampling from 1993 through 1999. As described above in the "Methodology" section of this report, water temperature and dissolved oxygen data collected from 1993 to 1999 was typically collected from the surface of Lake Oroville to a depth of 20 - 22 m (65.6 - 72.2 ft) below the water surface, while in 2002, water temperature and dissolved oxygen data were collected at greater depths, with data collected to depths ranging from 56 to 170 m (184 - 558 ft) below the water surface depending upon the sampling station location. The lack of deep water sampling in 1993 through 1999 results in an artificially small calculated volume of usable coldwater habitat, as explained blows.

Consider, for example, water temperature and dissolved oxygen data collected in August near the face of Oroville Dam, as illustrated in **Figure 5**. At this location in August, the volume of usable coldwater habitat available was 517 TAF in 1993, 240 TAF in 1995, 68 TAF in 1996, 315 TAF in 1997, 137 TAF in 1999, and 1242 TAF in 2002. The reason the calculated volume of coldwater habitat is smaller from 1993 through 1999 is because sampling was discontinued at 20 - 25 m depth below the surface, depending upon the sampling date. By looking at the water temperature and dissolved oxygen profiles in Figure 5, it is reasonable to suggest that had sampling continued deeper for each year from 1993 through 1999, some additional water, if not most of the water, below the point at which sampling was halted in those years would be usable with respect to water temperature and dissolved oxygen. However, absent actual data to indicate that this was the case, it is not possible to reasonably speculate on specifically what volume of water would have met the usable coldwater habitat criteria had sampling continued deeper in the vertical profile. As a result, the calculation of volume of usable coldwater habitat assumes that no additional usable coldwater habitat exists below the deepest sampling point, even if it is suspected that usable cold water habitat would have existed had sampling continued deeper in the water column. The result of this assumption is that the calculated average volumes of usable coldwater habitat in Lake Oroville from 1993 through 1999 presented in this analysis are almost certainly smaller than the actual average volume of water that meets both water temperature and dissolved oxygen criteria used to define usable coldwater salmonid habitat.

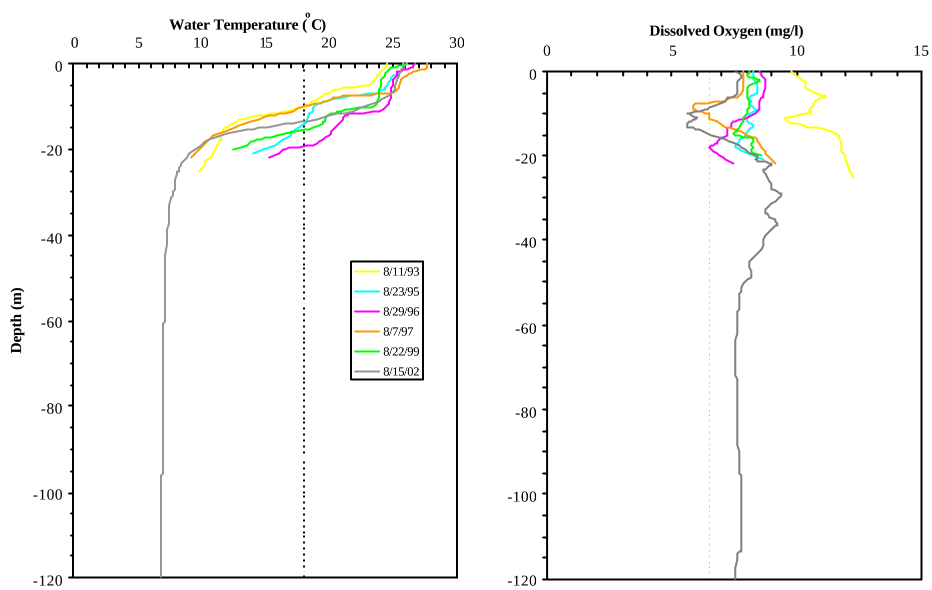

Figure 5. Water temperature and dissolved oxygen profiles collected near the face of Oroville Dam in August.

The calculated average volume of usable coldwater habitat Lake Oroville for each month and year is presented below in **Table 2**.

Table 2. Average volume (TAF) of usable coldwater habitat in Lake Oroville by month and year. -- no concurrently sampled water temperature and dissolved oxygen available at any sampling station for this month and year.

Year	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1993	--	--	--	--	980	716	--	530	--	442	--	757
1994	657	--	833	--	--	--	434	--	232	568	--	--
1995	--	--	--	--	731	--	--	213	23	58	767	750
1996	--	--	--	--	599	356	201	68	0	--	808	--
1997	773	--	570	820	--	398	294	250	197	--	593	--
1998	690	--	754	817	--	628	363	--	--	34	757	--
1999	--	832	--	861	--	465	172	149	--	135	666	--
2002	--	--	--	2149	1870	1683	1235	850	669	853	--	--
Monthly average	707	832	719	1162	1045	708	450	343	213	348	718	754

The month in which the calculated average volume of usable coldwater is lowest is September 1996, when the calculated average volume of usable coldwater habitat is 0 TAF. As described above, examining the water temperature and dissolved oxygen profiles for September 1996 illustrates that it would be reasonable to assume that had sampling continued deeper into the water column, water that meets both criteria for usable coldwater habitat would have been shown to exist. Water temperature and dissolved oxygen data for September 1996 is available from only two locations, the Goat Ranch sampling station (**Figure 6**) and the Bidwell Bar Bridge sampling station (**Figure 7**).

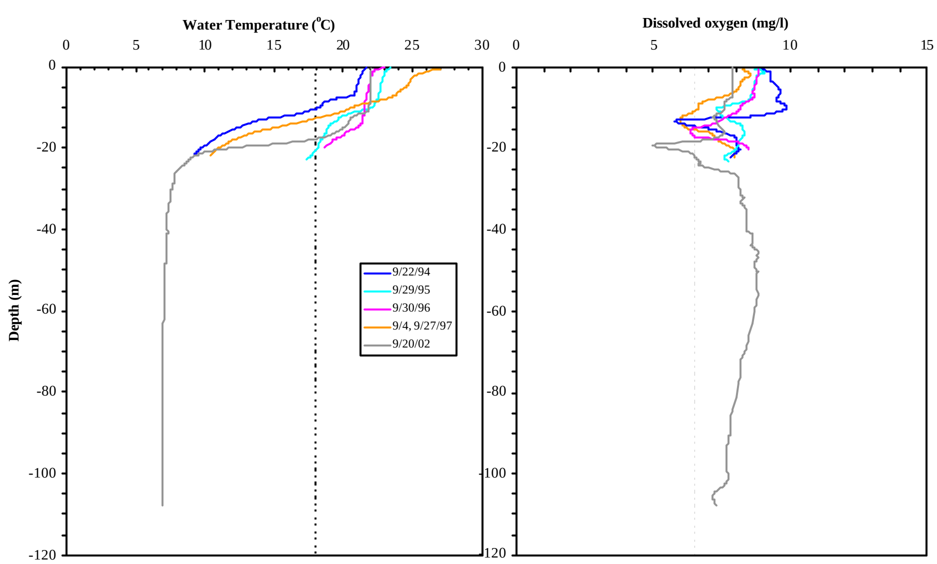

Figure 6. Water temperature and dissolved oxygen profiles collected in September at the Goat Ranch sampling station.

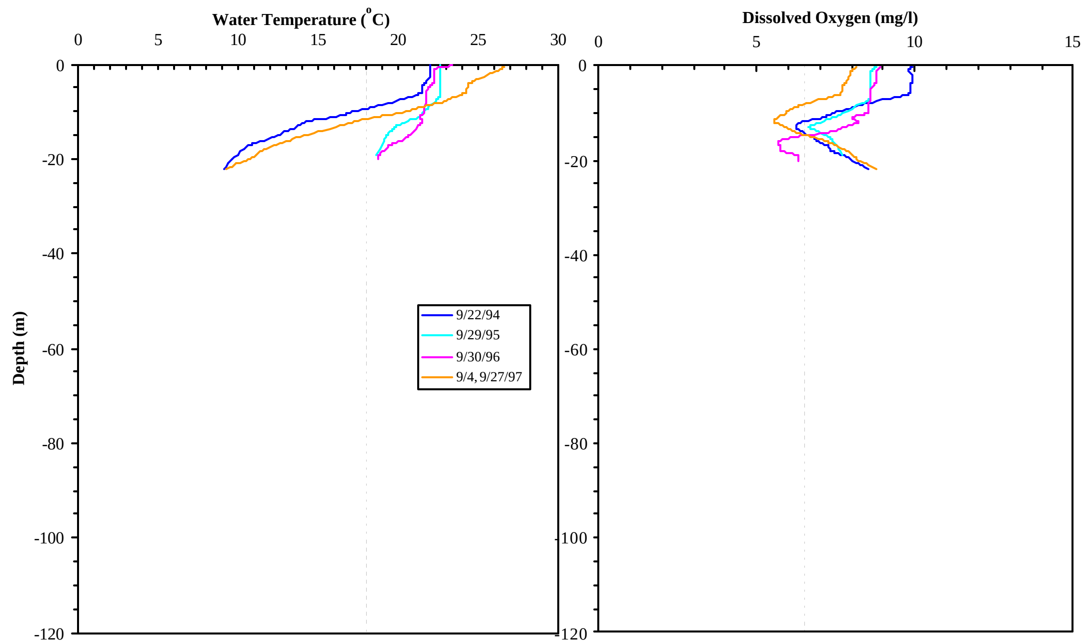

Figure 7. Water temperature and dissolved oxygen profiles collected in September at the Bidwell Bar Bridge sampling station.

Water temperature and dissolved oxygen profiles in September 1996 at the Goat Ranch sampling station (Figure 6, pink line) show that sampling did not continue deep enough into the water column to completely penetrate the thermocline. Had sampling continued deeper into the water column, water temperatures would have decreased to below the 18°C criteria and water that was usable with respect to water temperature would likely have been observed. Additionally, the dissolved oxygen profile during September 1996 suggests that it is likely that once usable water temperatures were reached, dissolved oxygen concentrations would meet the criteria for at least some volume of water. Similar statements can be made regarding the water temperature and dissolved oxygen profiles at the Bidwell Bar Bridge sampling location for September 1996 shown in Figure 7. However, it is not possible to reliably speculate regarding the volume of water for which both criteria would have been met had sampling continued deeper into the water column at either sampling station. Because it is reasonable to suggest, based on limnological profiles taken in other years during September and taken at points deeper in the water column, that there likely was useable coldwater habitat in September 1996 in Lake Oroville. Because it is not reasonable to speculate on what that volume may have been, September 1996 will not be considered the smallest average calculated volume of usable coldwater habitat in Lake Oroville. To say there was likely no usable coldwater habitat in Lake Oroville in September 1996 is not realistic because of the lack of deep water sampling and because of the general pattern of water temperature and dissolved oxygen relationship illustrated in other years in September in Lake Oroville. As a result, the smallest average volume of usable coldwater habitat calculated that will be utilized in further analysis is 23 TAF, the average volume of usable coldwater habitat occurring in September 1995. Although this volume will be used to represent the smallest average volume of coldwater habitat available in Lake Oroville at any time of the period of record, the above arguments apply to this calculation as well, and 23 TAF is likely to be an exceptionally conservative estimate of the smallest amount of usable coldwater habitat available at any time.

Visual inspection of the limnological profile above which indicate that, had water temperature and dissolved oxygen sampling continued deeper into the water column, water temperatures would have decreased to below the 18°C criteria. Model results describing water temperatures in Lake Oroville from SP-E7a support the suggestion that usable coldwater habitat exists below the thermocline. Model results confirm that even in summer months, the volume of water in Lake Oroville that meets the usable coldwater habitat criteria with respect to water temperature would far exceed the 413 acre-feet of water required to support salmonid stocking goals. Although SP-E7a model output does not include dissolved oxygen information, the model output suggests that sufficient volume of water below 18°C exists below the thermocline to support salmonid stocking goals.

The reservoir elevation at which usable coldwater habitat exists in Lake Oroville is illustrated for each sampling event at each sampling location in Figure 8 through Figure 13. The elevation is expressed in mean feet sea level (mls) and the depth from the water surface at which usable coldwater habitat water is available can be determined by subtracting the elevation at the surface of the water (top of bar for each date) from the elevation at which the color coding indicates that usable coldwater habitat exists. In general, during the late fall, winter and early spring months the elevation range of usable coldwater habitat extends to the surface of the water. This is expected because in the time following fall overturn through establishment of the thermocline in the spring, Lake Oroville is relatively well mixed, resulting in dissolved oxygen concentrations and water temperatures that meet the criteria for usable coldwater salmonid habitat throughout the water column. In the late spring, summer, and early fall months, the zone of usable coldwater salmonid habitat generally does not extend to the surface of the water column. Typically, this is the result of water temperatures that exceed the usable coldwater habitat criteria of 18°C, which is an expected result of thermal stratification. The zone of usable coldwater habitat in these months begins deeper in the water column at a depth that varies depending on the month, year, and sampling location, as illustrated in Figure 8 through Figure 13. Additionally, the zone of usable coldwater salmonid habitat extends deeper into the water column in 2002 than in any other year, for reasons discussed above included increased sampling depths during that sampling year. The gray shading in the bars in Figure 8 through Figure 13 illustrate areas of no data. Elevations containing no data reflect that no sampling occurred at those depths.

5.4 COMPARISON OF VOLUME OF USABLE COLDWATER HABITAT PER FISH IN LAKE OROVILLE TO VOLUME OF COLDWATER PER FISH PROVIDED IN OTHER SETTINGS

The calculation of usable coldwater habitat in Lake Oroville conducted for this analysis suggests that the smallest calculated volume of usable coldwater habitat in any month of any year over the period of record is 23,000 acre-feet of water (see Section 5.3 for further discussion). As previously calculated in Section 5.2, the volume of usable coldwater habitat required to support the current stocking goals is 413 acre-feet. Thus, using the most conservative estimate of the number of stocked salmonids that would be present in Lake Oroville at any given time, the volume of usable coldwater habitat available in the month with the lowest calculated average

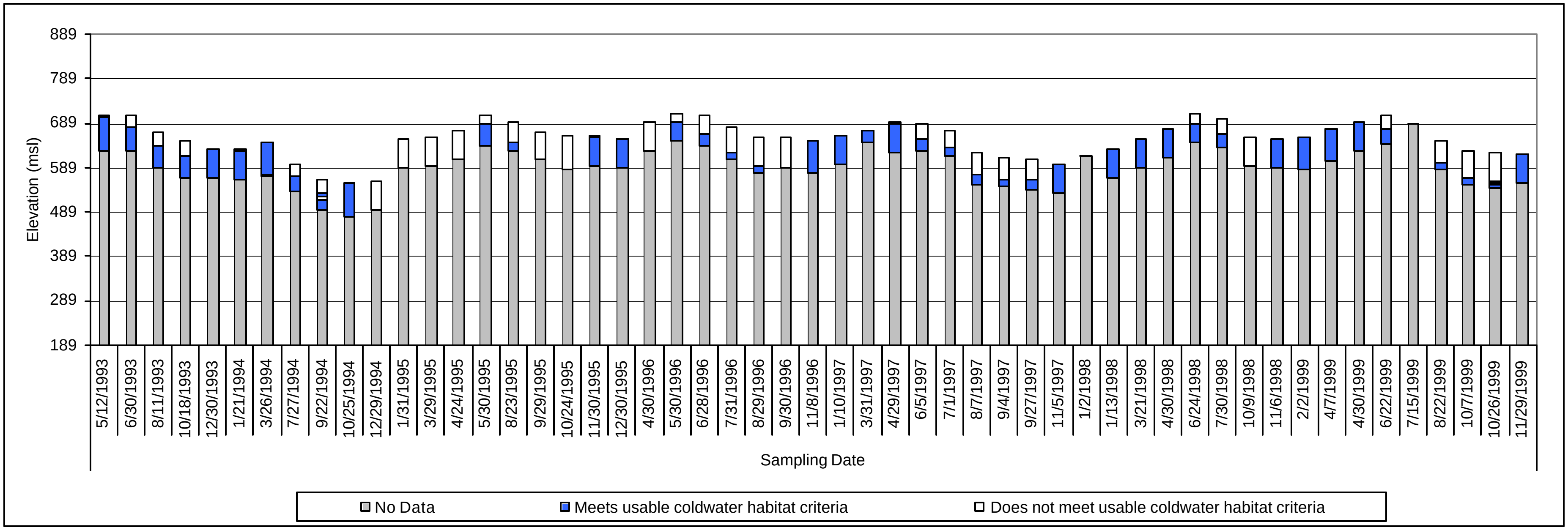

Figure 8. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the Bidwell Bar Bridge sampling station.

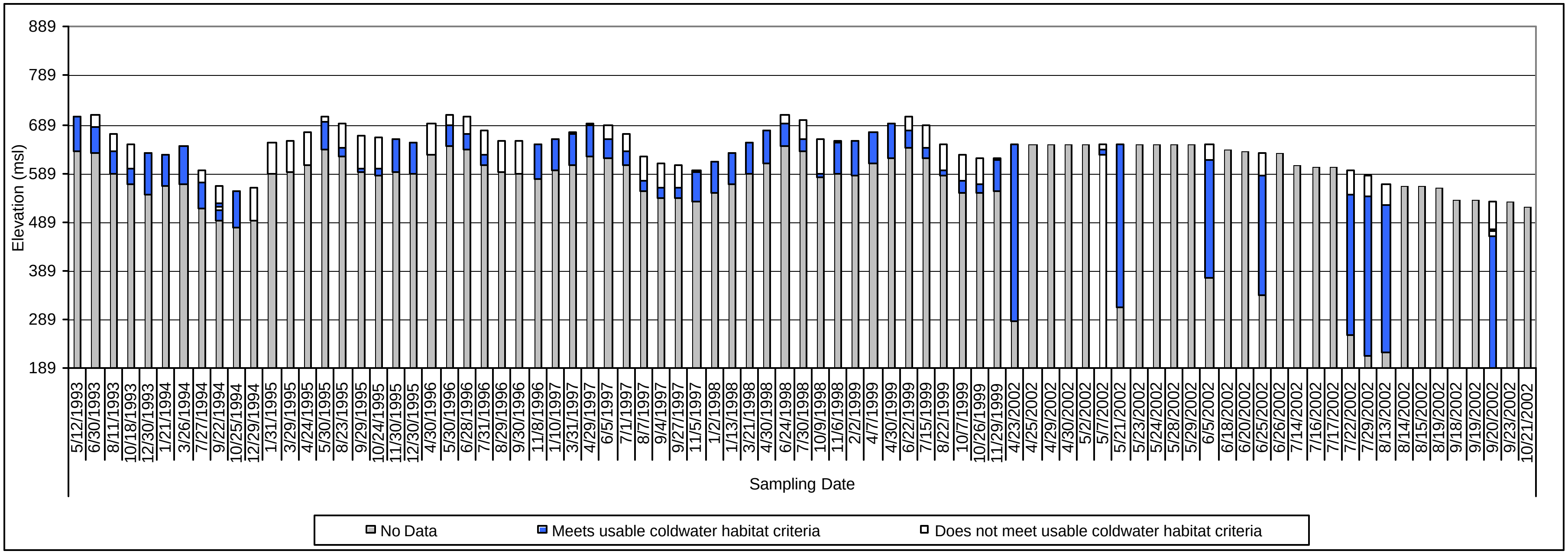

Figure 9. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the Goat Ranch and North Fork Arm sampling stations.

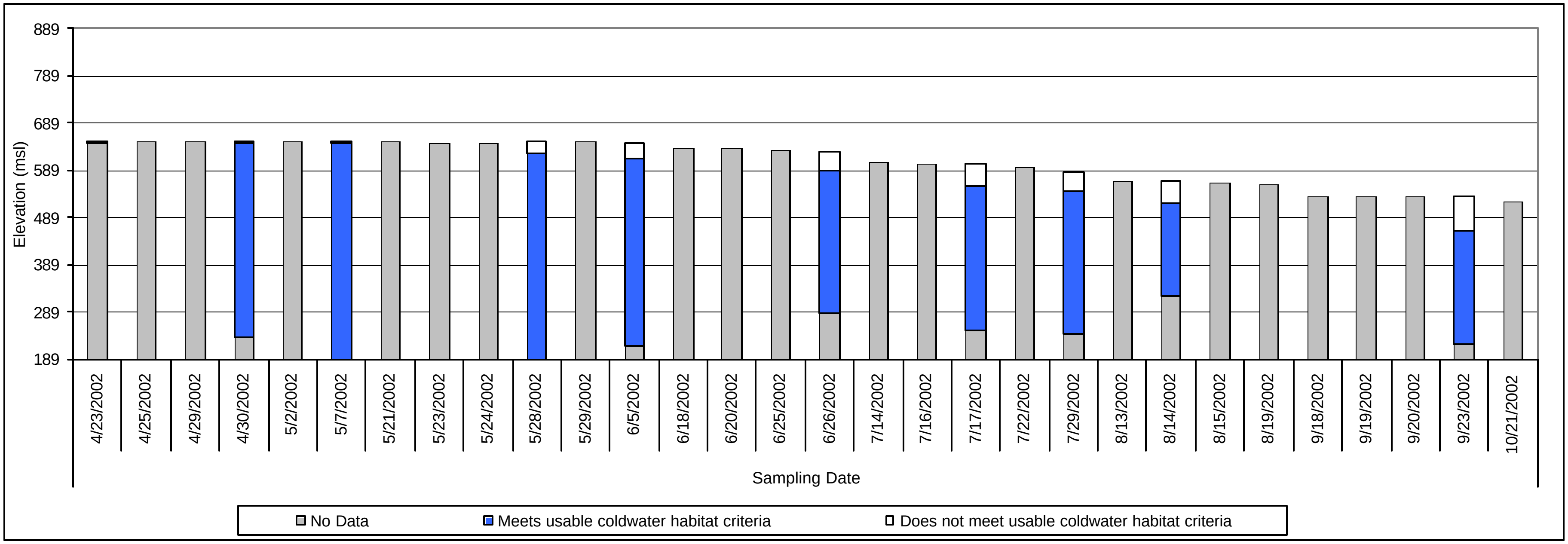

Figure 10. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the Main Lake sampling station.

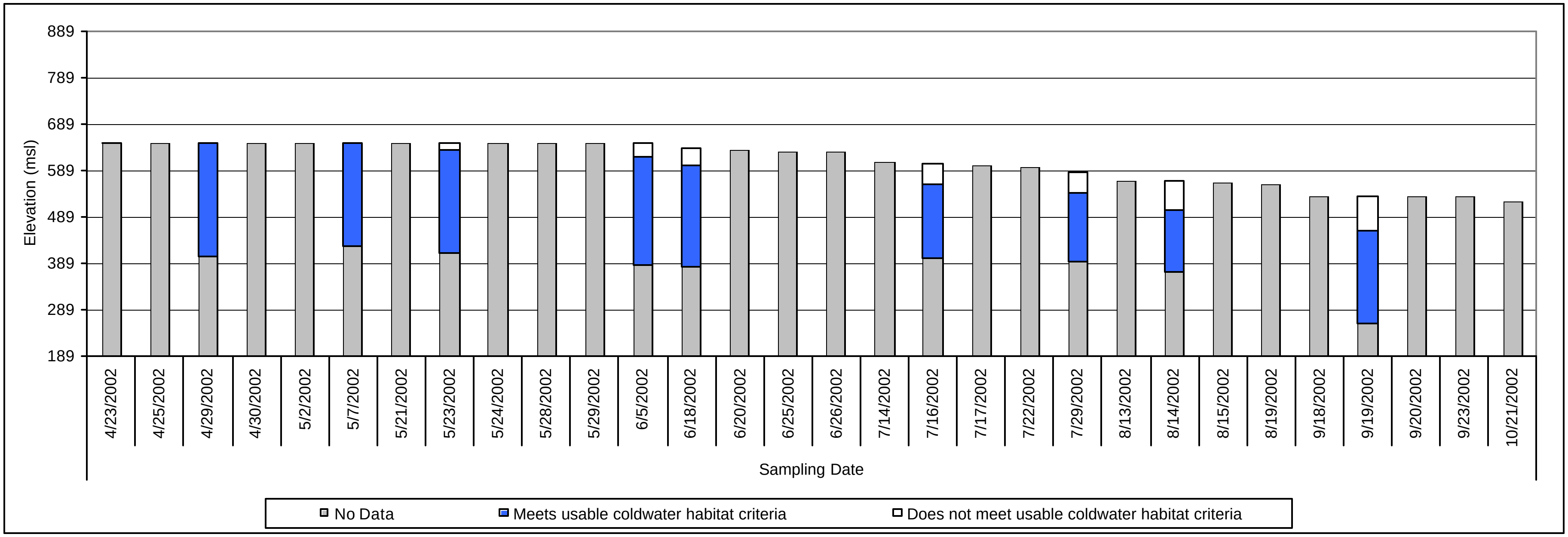

Figure 11. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the Middle Fork sampling station.

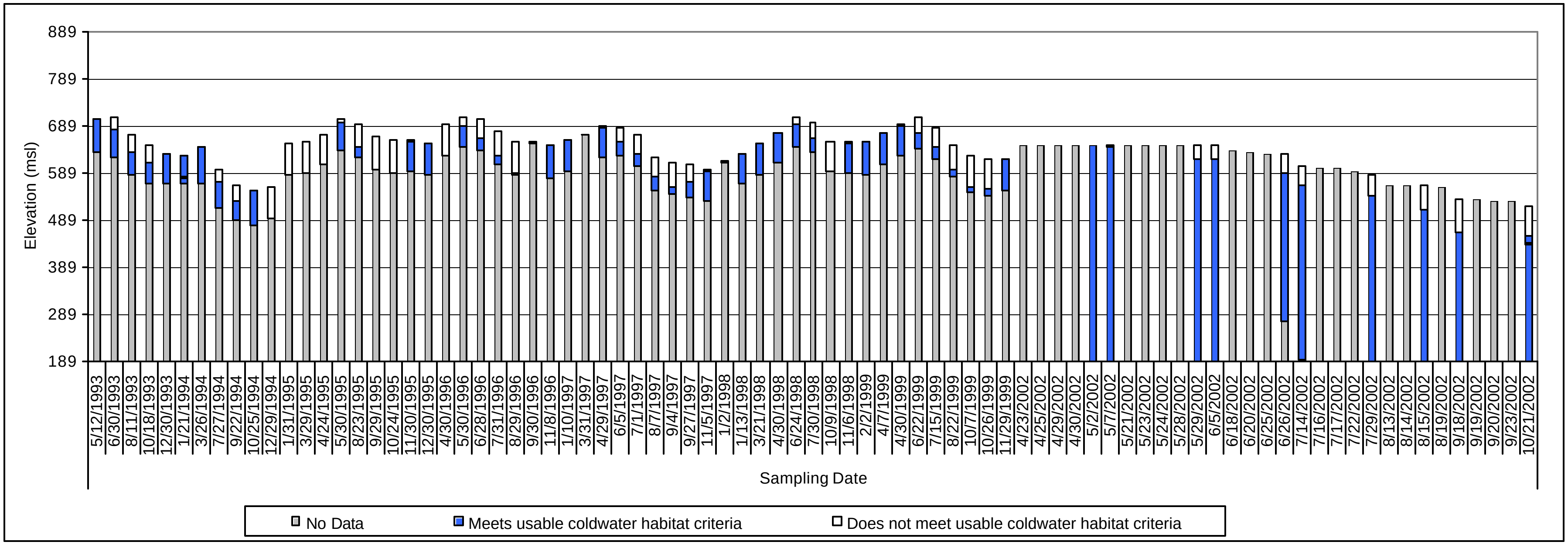

Figure 12. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the Oroville Dam near the face and the Oroville Dam sampling stations.

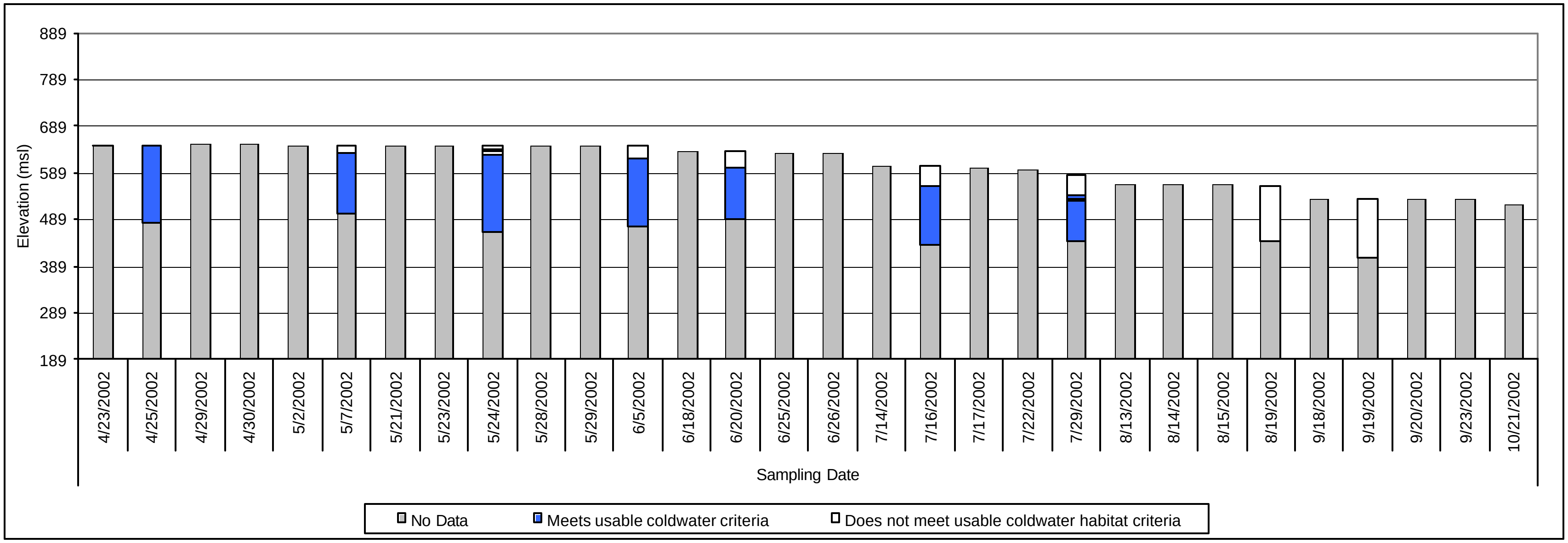

Figure 13. Elevation (msl) of water in Lake Oroville that meets usable coldwater habitat criteria at the South Fork sampling station.

volume of usable coldwater habitat in Lake Oroville during any month over the period of record is approximately 55.6 times greater than the volume of water suggested as required by even the most conservative stocking density estimates obtained from the literature review. In other words, if 510,000 salmonids were present in Lake Oroville, even in the month with the smallest calculated average volume of usable coldwater habitat, the volume of usable coldwater habitat per fish would be 55.6 m^3. Thus, even in the worst-case scenario (i.e., minimum calculated volume of usable coldwater habitat over the period of record), the volume of water per fish in Lake Oroville far exceeds the volume of water provided per fish in any other types of setting. Additionally, as discussed in Section 5.3 of this report, the minimum calculated volume of usable coldwater habitat over the period of record is likely an underestimate of the actual volume usable of coldwater habitat available due to cessation of water temperature and dissolved oxygen data collection at approximately 23 meters below the water surface.

The comparison of loading densities in settings that are generally considered space-limited such as hatcheries and commercial net-pen operations to fish densities in Lake Oroville was conducted because the lowest maximum densities in systems that are generally considered space-limited represent a measure of the volume of water required if space is the primary variable being considered. Although the focus of this task did not include an analysis of food availability, existing data regarding food availability in Lake Oroville may provide additional value to this analysis. If coldwater habitat that is usable with respect to water temperature and dissolved oxygen is present, but no forage base is present in the zone of Lake Oroville containing physically usable habitat, the zone of physically usable habitat in Lake Oroville may not provide the forage necessary for stocked salmonids. Existing data regarding depth distribution of forage base from the five-year joint conducted to establish stocking recommendations is briefly reviewed below to assess the availability of forage base within the zone of usable coldwater habitat.

During the joint five-year study conducted to establish stocking recommendations, stomach analysis was conducted in order to determine the forage base for Chinook salmon. In this study, stomach were collected from 206 Chinook salmon to determine prey species preference (DWR 2000). Forty-eight (23%) of the collected stomachs were empty (DWR 2000). Total stomach contents by volume consisted of approximately 28% wakasagi, 29% threadfin shad, and 32% unknown fish remains (DWR 2000). Insect larvae and zooplankton made up a small percentage of the stomach contents (DWR 2000). Predation on wakasagi by Chinook salmon as small as 240 mm TL (the size of Chinook salmon in Lake Oroville at approximately 10 months of age) was confirmed (DWR 2000). Thus, Chinook salmon in Lake Oroville were highly piscivorous and threadfin shad, wakasagi, and unidentified fish remains comprised 89 percent of the stomach contents analyzed (DWR 2000). Hydroacoustic surveys were then conducted to assess the depth distribution of forage base in Lake Oroville. Hydroacoustic surveys were conducted monthly to characterize prey species abundance and distribution (DWR 2000). Monthly hydroacoustic survey data was grouped into quarterly abundance indices (DWR 2000). Separate forage abundance indices were developed for each of three depth strata: 0-12 meters, 12-24 meters, and over 24 meters (DWR 2000). Due to the extreme depths of the main body of Lake Oroville, a maximum recording depth was set to 30 or 45 meters depending on the distribution of target fish in order to achieve sufficiently detailed tracings of target fish (DWR 2000). The hydroacoustic survey results suggest that there is always forage base present at that the depths that constitute the calculated zone of usable coldwater habitat, as illustrated in **Figure 14**. Because the results of this survey are indices illustrating only relative abundance, it is not possible to speculate regarding whether the abundance of forage base is sufficient to support the salmonid stocking goals, but the results do illustrate that there is forage base present in Lake Oroville in the zones in which usable coldwater habitat exists.

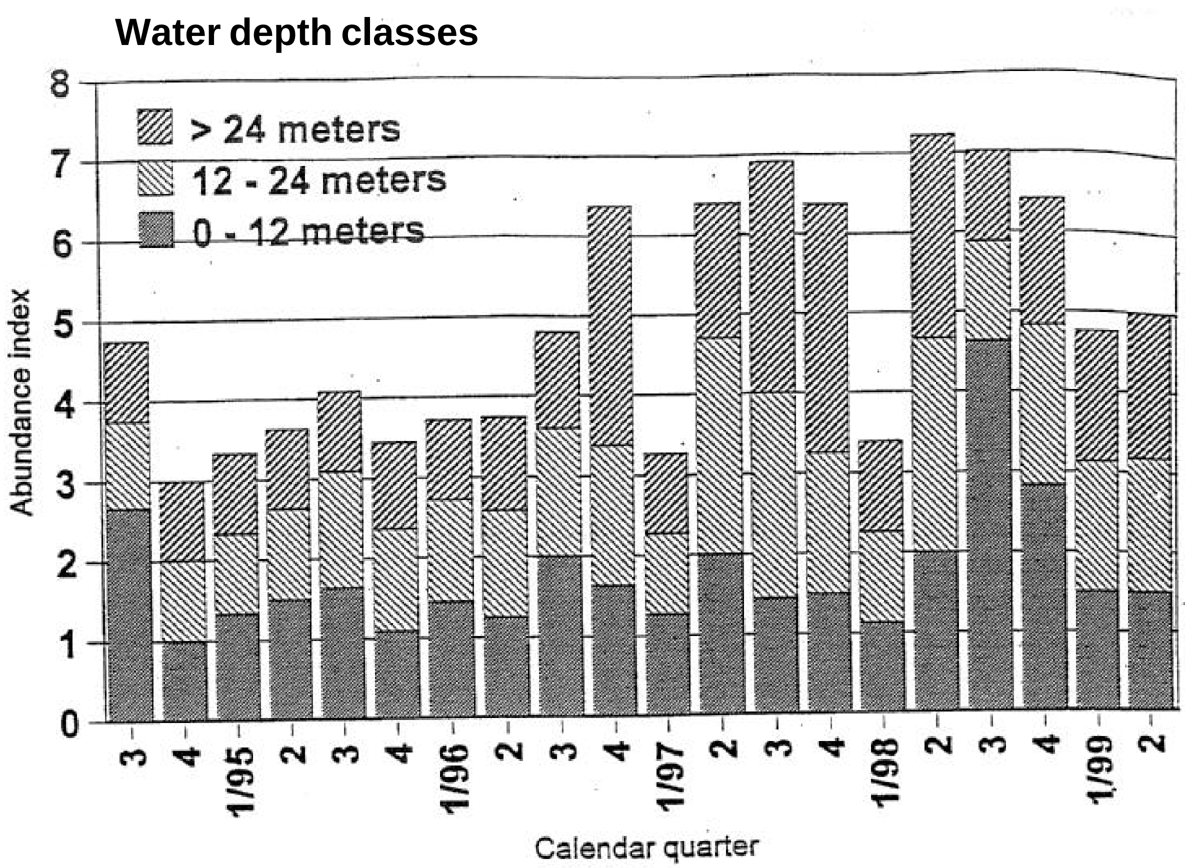

Figure 14. Index of forage abundance from hydroacoustic sampling in Lake Oroville, July 1995 through June 1999. Source: (DWR 2000)

6.0 CONCLUSIONS

This analysis utilized water temperature and dissolved oxygen data collected over 51 months in Lake Oroville in order to calculate the volume of usable coldwater habitat that would be available for salmonids stocked in Lake Oroville. Because of the highly conservative assumptions used throughout the analysis, the analysis provides an exceptionally conservative estimate of the volume of usable coldwater habitat in Lake Oroville, which almost certainly results in an underestimation of the actual volume of usable coldwater habitat available in Lake Oroville. The analysis conducted suggests that even in the years with the smallest calculated volume of usable coldwater habitat, the volume of usable coldwater per fish in Lake Oroville far exceeds the volume of water provided per fish in any other types of setting, such as hatcheries and experimental and commercial net pens. Additionally, available information regarding depth distribution of forage base suggests that forage base is present in Lake Oroville in the zones in which usable coldwater habitat exists. Therefore, continued operation of the Oroville facilities in a manner consistent with current operations would be expected to result in a sufficient volume of usable coldwater habitat to support current salmonid stocking recommendations in Lake Oroville.

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OROVILLE FERC RELICENSING
(PROJECT NO. 2100)

FINAL REPORT
SP-F3.1 TASK 2B

APPENDIX A
WATER TEMPERATURE AND DISSOLVED OXYGEN PROFILES COLLECTED IN LAKE OROVILLE (1993-1999, 2002)

EVALUATION OF THE ABILITY OF LAKE OROVILLE'S COLDWATER POOL TO SUPPORT SALMONID STOCKING RECOMMENDATIONS

MARCH 2003

OROVILLE FERC RELICENSING
(PROJECT NO. 2100)

FINAL REPORT
SP-F3.1 TASK 2B

APPENDIX B
JUVENILE COHO AND CHINOOK SALMON HATCHERY REARING DENSITIES

EVALUATION OF THE ABILITY OF LAKE OROVILLE'S COLDWATER POOL TO SUPPORT SALMONID STOCKING RECOMMENDATIONS

MARCH 2003

Juvenile Coho and Chinook Salmon Hatchery Rearing Densities

The following table summarizes rearing pond densities (fish/m^3), and average final or release fork length (FL, cm) and weight (g) of juvenile (fingerling or yearling) coho and Chinook salmon from various reported rearing hatchery experiments conducted in raceways or ponds.

SPECIES	Pond Density (fish/m^3)	Final Average FL (cm)	Final Average Weight (g)	Rearing Period	Hatchery	Rearing Pond Characteristics	Reference
Chinook (F)	426		11.6	4/15/93 - 5/20/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	429		11.2	4/18/90 - 5/17/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	429		11.7	4/18/91 - 5/16/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	433		13.8	4/16/92 - 5/21/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	643		6.0	3/18/93 - 4/15/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	646		7.4	3/16/90 - 4/18/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	646		6.6	3/21/91 - 4/18/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	653		8.6	3/5/92 - 4/16/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	853		10.4	4/15/93 - 5/20/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	854		11.8	4/18/91 - 5/16/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	861		13.3	4/16/92 - 5/21/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	864		10.1	4/18/90 - 5/17/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,276		10.4	4/15/93 - 5/20/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,279		12.9	4/16/92 - 5/21/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,284		11.2	4/18/91 - 5/16/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,285		6.8	3/21/91 - 4/18/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,289		5.5	3/18/93 - 4/15/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,295		10.0	4/18/90 - 5/17/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,298		6.8	3/16/90 - 4/18/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,302		7.9	3/5/92 - 4/16/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,703		12.7	4/16/92 - 5/21/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,704		10.2	4/15/93 - 5/20/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,714		11.2	4/18/91 - 5/16/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,721		10.4	4/18/90 - 5/17/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,930		8.1	3/5/92 - 4/16/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,934		5.6	3/18/93 - 4/15/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,934		6.3	3/21/91 - 4/18/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	1,946		7.0	3/16/90 - 4/18/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	2,573		8.0	3/5/92 - 4/16/92	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	2,584		6.5	3/21/91 - 4/18/91	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)

Juvenile Coho and Chinook Salmon Hatchery Rearing Densities (Cont.)

SPECIES	Pond Density (fish/m³)	Final Average FL (cm)	Final Average Weight (g)	Rearing Period	Hatchery	Rearing Pond Characteristics	Reference
Chinook (F)	2,589		7.0	3/16/90 - 4/18/90	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	2,592		5.4	3/18/93 - 4/15/93	Spring Creek (WA)	91.2 m^3 ponds (22.9 x 5.2 x 0.8)	Banks and LaMotte (2002)
Chinook (F)	241		46.3	4/15/84 - 10/8/84	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	241		35.8	4/15/86 - 9/16/86	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	245		42.0	4/15/85 - 10/9/85	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	246		47.3	4/15/83 - 10/10/83	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	315		45.4	4/15/83 - 10/10/83	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	335		33.9	4/15/86 - 9/16/86	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	342		45.9	4/15/84 - 10/8/84	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	347		39.4	4/15/85 - 10/9/85	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	413		47.8	4/15/83 - 10/10/83	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	420		31.8	4/15/86 - 9/16/86	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	424		41.6	4/15/85 - 10/9/85	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (F)	436		44.5	4/15/84 - 10/8/84	Elk River (OR)	111.3 m^3 Burrows' ponds (22.9 x 5.4 x 0.9)	Ewing and Ewing (1995)
Chinook (Sp)	50		90.8	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	50		133.5	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	51		90.8	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	52		133.5	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	102		100.9	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	104		100.9	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	110		122.7	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	111		122.7	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	158		113.5	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	158		119.5	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	159		119.5	? - May 1976	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	160		113.5	? - May 1977	Colwitz (WA)	558 m^3 Burrows' ponds (30.5 x 6.1 x 3)	Ewing and Ewing (1995)
Chinook (Sp)	212		31.2	4/3/78 - 5/17/79	Little Port Walter (AK)	22.65 m^3 ponds	Ewing and Ewing (1995)

Juvenile Coho and Chinook Salmon Hatchery Rearing Densities (Cont.)

SPECIES	Pond Density (fish/m^3)	Final Average FL (cm)	Final Average Weight (g)	Rearing Period	Hatchery	Rearing Pond Characteristics	Reference
Chinook (Sp)	358		31.8	4/3/78 - 5/17/79	Little Port Walter (AK)	22.65 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	371		28.2	4/3/78 - 5/17/79	Little Port Walter (AK)	22.65 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	389		17.7	7/15/82 - 5/15/83	Deer Mountain (AK)	Swedish-style 21.9 m^3 tanks (d = 5)	Ewing and Ewing (1995)
Chinook (Sp)	770		16.6	7/15/82 - 5/15/83	Deer Mountain (AK)	Swedish-style 21.9 m^3 tanks (d = 5)	Ewing and Ewing (1995)
Chinook (Sp)	971		10.1	4/3/78 - 5/17/79	Little Port Walter (AK)	11.33 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	1,787		17.8	7/15/82 - 5/15/83	Deer Mountain (AK)	Swedish-style 21.9 m^3 tanks (d = 5)	Ewing and Ewing (1995)
Chinook (Sp)	2,004		10.2	4/3/78 - 5/17/79	Little Port Walter (AK)	11.33 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	2,471		9.7	4/3/78 - 5/17/79	Little Port Walter (AK)	11.33 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	2,754		10.3	4/3/78 - 5/17/79	Little Port Walter (AK)	11.33 m^3 ponds	Ewing and Ewing (1995)
Chinook (Sp)	3,742		9.9	4/3/78 - 5/17/79	Little Port Walter (AK)	11.33 m^3 ponds	Ewing and Ewing (1995)
Coho	135	13.3	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	135	13.5	25.2	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	144	13.2	22.7	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	164	13.2	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	164	13.5	25.2	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	174	12.9	21.6	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	193	13.2	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	194	13.3	23.9	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	210	13.0	21.6	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	239	13.2	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	239	13.5	26.7	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	253	12.8	20.6	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	279	13.2	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	279	13.5	25.2	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	300	13.0	21.6	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)

Juvenile Coho and Chinook Salmon Hatchery Rearing Densities (Cont.)

SPECIES	Pond Density (fish/m^3)	Final Average FL (cm)	Final Average Weight (g)	Rearing Period	Hatchery	Rearing Pond Characteristics	Reference
Coho	339	13.2	23.9	11/2/82 - 5/27/83	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	339	13.4	25.2	11/18/83 - 5/5/84	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	358	12.9	21.6	11/5/81 - 5/23/82	Washougal (WA)	301 m^3 ponds (41.1 x 5.3 x 1.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	527	11.8	17.7	7/27/78 - 6/4/79	Capilano River (BC)	124 m^3 raceways (24.6 x 5.6 x 0.9)	Fagerlund et al. (1981)
Coho	712		22.7	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)
Coho	712		23.4	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)
Coho	726	11.6	16.6	7/27/78 - 6/4/79	Capilano River (BC)	124 m^3 raceways (24.6 x 5.6 x 0.9)	Fagerlund et al. (1981)
Coho	850	13.5	28.4	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	851	11.6	15.4	7/27/78 - 6/4/79	Capilano River (BC)	124 m^3 raceways (24.6 x 5.6 x 0.9)	Fagerlund et al. (1981)
Coho	851	13.0	22.7	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	859	10.0	11.2	10/14/74 - 6/15/75	Capilano River (BC)	108 m^3 Burrows' ponds	Fagerlund et al. (1979)
Coho	864	13.3	25.2	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	952	10.0	14.4	10/14/74 - 6/15/75	Capilano River (BC)	108 m^3 Burrows' ponds	Fagerlund et al. (1979)
Coho	955	12.8	22.7	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,000	13.3	25.2	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,006	13.6	26.7	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,008	11.1	13.8	7/27/78 - 6/4/79	Capilano River (BC)	124 m^3 raceways (24.6 x 5.6 x 0.9)	Fagerlund et al. (1981)
Coho	1,033	13.5	25.2	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,052	13.6	26.7	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,055	13.3	23.9	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,080	10.0	9.1	10/14/74 - 6/15/75	Capilano River (BC)	108 m^3 Burrows' ponds	Fagerlund et al. (1979)
Coho	1,103	13.0	22.7	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,119	13.6	23.9	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,211	13.6	28.4	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,239	13.3	25.2	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)

Juvenile Coho and Chinook Salmon Hatchery Rearing Densities (Cont.)

SPECIES	Pond Density (fish/m^3)	Final Average FL (cm)	Final Average Weight (g)	Rearing Period	Hatchery	Rearing Pond Characteristics	Reference
Coho	1,248	13.5	26.7	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,269	12.9	25.2	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,376	13.7	26.4	10/4/82 - 5/3/83	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,401	13.7	26.7	10/6/83 - 5/3/84	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	1,423		23.7	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)
Coho	1,423		24.9	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)
Coho	1,433	12.7	23.9	9/21/81 - 5/3/82	Colwitz (WA)	446.5 m^3 ponds (30.5 x 6.1 x 2.4)	Ewing and Ewing (1995); Hopley et al. (1993)
Coho	2,135		23.4	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)
Coho	2,135		24.2	6/1/81 - 6/1/82	Willard (WA)	35.1 m^3 raceways (24.4 x 2.4 x 0.6)	Ewing and Ewing (1995); Banks (1992)

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OROVILLE FERC RELICENSING
(PROJECT NO. 2100)

FINAL REPORT
SP-F3.1 TASK 2B

APPENDIX C
DENSITIES OF SALMONIDS RAISED IN EXPERIMENTAL AND COMMERCIAL NET-PENS AND CAGES

EVALUATION OF THE ABILITY OF LAKE OROVILLE'S COLDWATER POOL TO SUPPORT SALMONID STOCKING RECOMMENDATIONS

MARCH 2003

Densities of salmonids raised in experimental and commercial net-pens and cages

SPECIES	Stage	Numbers	Density (fish/m^3)	Volume (m^3)	Description	Location	Reference
Atlantic salmon	Parr (26 g)	5,000	214	23	Experimental floating lake cage (3.6 m x 3.6 m x 1.8 m)	Indian Brook Research Station, Newfoundland (Canada)	Pepper et al. (1987)
Atlantic salmon	Parr (26 g)	10,000	429	23	Experimental floating lake cage (3.6 m x 3.6 m x 1.8 m)	Indian Brook Research Station, Newfoundland (Canada)	Pepper et al. (1987)
Atlantic salmon	Parr (26 g)	15,000	643	23	Experimental floating lake cage (3.6 m x 3.6 m x 1.8 m)	Indian Brook Research Station, Newfoundland (Canada)	Pepper et al. (1987)
Atlantic salmon	Smolt	3,000	6	500	Commercial floating net-cages of cubic or cylindrical net bags often moored in rafts or flotillas.	Norway coast, marine protected sites.	Laird and Needham (1988)
Atlantic salmon	Smolt	5,000	10	500	Commercial floating net-cages of cubic or cylindrical net bags often moored in rafts or flotillas.	Norway coast, marine protected sites.	Laird and Needham (1988)
Atlantic salmon	Smolt	20,000	13	1,500	Commercial Polar-cirkel cage, 25-m diameter.	Shetland, Faroes and Lofoten Islands, marine hostile areas.	Laird and Needham (1988)
Atlantic salmon	Smolt	300,000	2	182,000	Commercial sea enclosure, 3.5-hectare strip of water between two islands, with a concrete dam at each end.	Norway lochs or fjords	Laird and Needham (1988)
Atlantic salmon	Smolt	6,000	30	200	Commercial net-cage	Scotland	Laird and Needham (1988)
Atlantic salmon	Smolt	8,000	40	200	Commercial net-cage	Scotland	Laird and Needham (1988)
Atlantic salmon	Smolt	10,000	20	500	Commercial net-cage	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	10,000	10	1,000	Commercial net-cage	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	10,000	9	1,100	Commercial Polar-cirkel cage, 19-m diameter, 4-m depth.	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	15,000	11	1,400	Commercial Polar-cirkel cage, 19-m diameter, 5-m depth.	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	15,000	10	1,550	Commercial Polar-cirkel cage, 22-m diameter, 4-m depth.	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	20,000	10	1,950	Commercial Polar-cirkel cage, 22-m diameter, 5-m depth.	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Smolt	20,000	10	2,000	Commercial Polar-cirkel cage, 25-m diameter, 4-m depth.	Shetland and Norway	Laird and Needham (1988)

Densities of salmonids raised in experimental and commercial net-pens and cages (Cont.)

SPECIES	Stage	Numbers	Density (fish/m^3)	Volume (m^3)	Description	Location	Reference
Atlantic salmon	Smolt	25,000	10	2,500	Commercial Polar-cirkel cage, (5-m H, 25-m D)	Shetland and Norway	Laird and Needham (1988)
Atlantic salmon	Kelt[1] (781 g)	250	6	45	Experimental cylindrical net-cage (6.1-m H, 3.1-m D)	Indian Pond, Newfoundland (Canada)	Pepper and Parsons (1987)
Atlantic salmon	Kelt (1,300 g)	286	1	205	Experimental cylindrical net-cage (7-m H, 6.1-m D)	Shoal Arm, Newfoundland (Canada)	Pepper and Parsons (1987)
Chinook salmon	Fingerling (6.2 g)	220	2	91	Experimental cylindrical net-cage (12-m H, 3.1-m D)	Saanish Inlet, BC (Canada)	English, K.K. (1980)
Chinook salmon	Fingerling (8-10 g)	7,500	44	172	Experimental net-pen with artificial freshwater lens system (3.7 m x 3.7 m x 3.4 m)	Little Port Walter (AK)	Thrower et al. (1998)
Coho salmon	Smolt (150 g)	5,000	7	700	Commercial square net-pen cages (10 m x 10 m x 7 m)	Japan, Shizugawa Bay	Stickney (1991)
Coho salmon	Smolt (150 g)	10,000	6	1,690	Commercial square net-pen cages (3 m x 3 m x 10m)	Japan, Onagawa Bay	Stickney (1991)
Coho salmon	Smolt (150 g)	10,000	160	63	Commercial land-based and floating tanks (5 m x 5 m x 2.5m)	Japan, various bays	Stickney (1991)
Coho salmon	Smolt (20-25 g)	20,000	25	800	Commercial floating net-pen	Puget Sound (WA)	Stickney (1991)
Rainbow trout	Fingerling (15-20 cm)	500	276	2	Commercial floating fish cage (1.2 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Rainbow trout	Fingerling (15-20 cm)	1,000	276	4	Commercial floating fish cage (2.4 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Rainbow trout	Fingerling (15-20 cm)	2,000	276	7	Commercial floating fish cage (2.4 m x 2.4 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Rainbow trout	Fingerling (15-20 cm)	400	281	1	Commercial cylindrical floating fish cage (1.2-m H, 1.2-m D)	US North Central Region	Swann et al. (1994)
Rainbow trout	Fingerling (26 g)	100	100	1	Experimental tank	Saint Pée sur Nivelle, France	Boujard, T. et al. (2002)
Rainbow trout	Fingerling (26 g)	300	300	1	Experimental tank	Saint Pée sur Nivelle, France	Boujard, T. et al. (2002)
Rainbow trout	Fingerling (26 g)	500	500	1	Experimental tank	Saint Pée sur Nivelle, France	Boujard, T. et al. (2002)

[1] Post-spawned grilse

Densities of salmonids raised in experimental and commercial net-pens and cages (Cont.)

SPECIES	Stage	Numbers	Density (fish/m^3)	Volume (m^3)	Description	Location	Reference
Brook trout	Fingerling (15-20 cm)	500	276	2	Commercial floating fish cage (1.2 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brook trout	Fingerling (15-20 cm)	1,000	276	4	Commercial floating fish cage (2.4 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brook trout	Fingerling (15-20 cm)	2,000	276	7	Commercial floating fish cage (2.4 m x 2.4 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brook trout	Fingerling (15-20 cm)	400	281	1	Commercial cylindrical floating fish cage (1.2-m H, 1.2-m D)	US North Central Region	Swann et al. (1994)
Brown trout	Fingerling (15-20 cm)	500	276	2	Commercial floating fish cage (1.2 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brown trout	Fingerling (15-20 cm)	1,000	276	4	Commercial floating fish cage (2.4 m x 1.2 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brown trout	Fingerling (15-20 cm)	2,000	276	7	Commercial floating fish cage (2.4 m x 2.4 m x 1.2 m).	US North Central Region	Swann et al. (1994)
Brown trout	Fingerling (15-20 cm)	400	281	1	Commercial cylindrical floating fish cage (1.2-m H, 1.2-m D)	US North Central Region	Swann et al. (1994)

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